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MAGLIF: Theorist's Perspective*

LLNL Fusion Energy Sciences Program

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General parameter domain:

S. A. Slutz M. C. Herrmann, R. A. Vesey, et al., Phys. Plasmas, **17**, 05603 (2010)

D.B. Sinars, S.A. Slutz, M.C, Herrmann M. C. et al. Phys Rev Lett.**105**,185001 (2010)

D.B. Sinars, S.A. Slutz, M.C. Herrmann et al. Phys. Plasmas   **18** , 056301 (2011)

D.B. Sinars, K.J. Peterson, S.A. Slutz S.A. et al. IEEE Transactions on Plasma Science   **39**, 2408 (2011)

S.A. Slutz and R. A. Vesey, Phys Rev Lett., **108**, 025003 (2012)

Global issues:

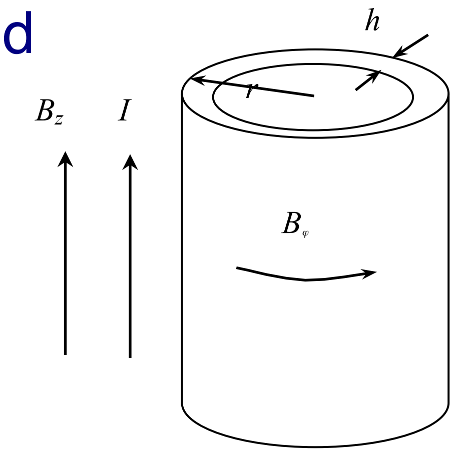
Batch burn vs. propagating burn

Stand-off

Applications for hybrids and fission waste incineration

Specific physics issues

Liner stability during acceleration and rebound



- Stabilizing effect of an axial magnetic field
- Effects of resistivity and viscosity on the liner stability
- The role of volumetric perturbations

Compression of the target plasma

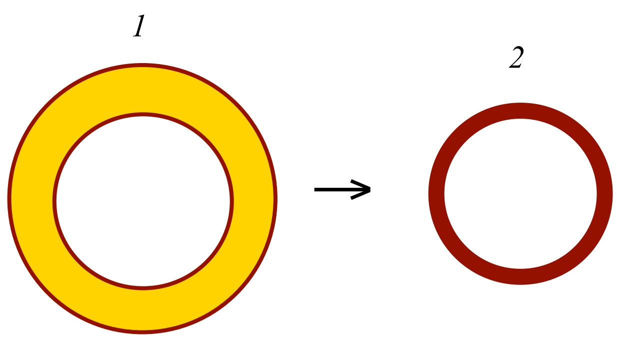
- Plasma transport, including anomalous transport
- Cooling flows
- Tangled magnetic field

Plasma preheat

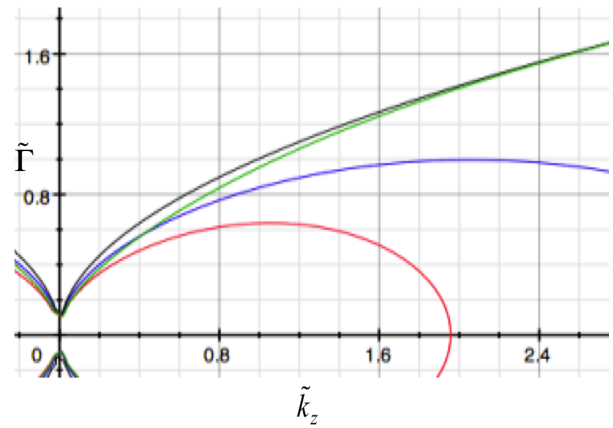
Liner stability

Axial magnetic field embedded in the liner has a strong stabilizing effect on the *m*=0 modes during acceleration phase

A strong embedded axial field can be created by embedding a bias field into a thicker compressible liner (conceptually, a foam or a set of thin cylindrical shells)



Starting from a thick, porous, easily compressible liner or a liner made of several thin shells (the field inside will become roughly equal to the drive field)



$$\tilde{\Gamma} = \Gamma\sqrt{h/g}$$
$$\tilde{k}_z = k_z h$$

Black curve: B_L=0

Red curve: B_L=B_D

References to earlier work: D. Ryutov, M. Derzon, K. Matzen. Rev. Mod. Phys., 72, 167 (2000)

Liner stability (cont)

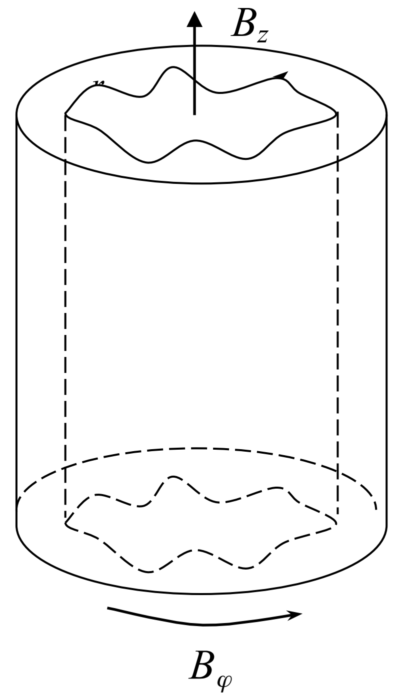
During the deceleration phase, the m=0 mode is strongly stabilized by the axial field in the imploded plasma, with the growth factor at that stage barely approaching unity*.

* D.D. Ryutov. Phys. Plasmas, **18**, 064509, 2011.

Liner stability (cont)

During the deceleration phase, the *m*=0 mode is strongly stabilized by the axial field in the imploded plasma, with the growth factor at that stage barely approaching unity*.

The fastest growing mode at this stage is the flute mode (independent on z). The growth factor can be significant for large-enough *m* numbers. Has to be studied more carefully



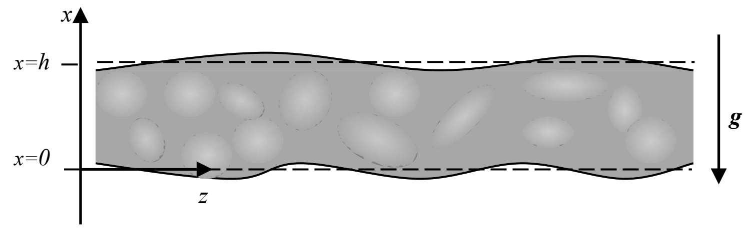
* D.D. Ryutov. Phys. Plasmas, **18**, 064509, 2011.

Liner stability (cont)

Dissipative processes seem to play a subdominant role for the proposed experiment. The finite resistivity may cause some modest reduction of the growth rate of the sausage mode during the acceleration stage and some modest increase of the growth rate of this mode at the deceleration stage. The viscosity is small.

Liner stability (cont)

There exists a remarkably simple technique for including the volumetric perturbations in the stability analysis*.



Auxiliary surface perturbations (with tildas):

$$\tilde{\xi}_u = \xi_u + \frac{1}{\cosh(kh)}\int_0^h \frac{\delta\rho(x_1)}{\rho_0}\cosh(kx_1)dx_1 \quad \tilde{\xi}_l = \xi_l - \frac{1}{\cosh(kh)}\int_0^h \frac{\delta\rho(x_1)}{\rho_0}\cosh(kh-kx_1)dx_1 .$$

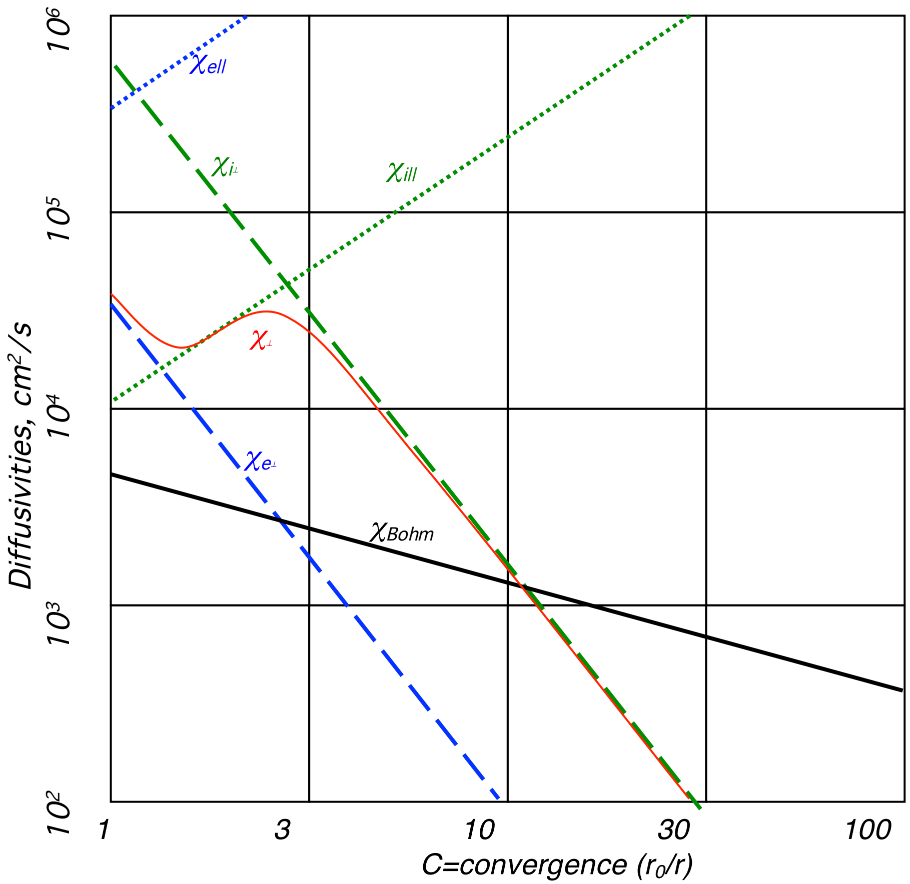
The second terms in these equations represent the contribution of volumetric perturbations.

Dynamic equations accounting for perturbations at both interfaces:

$$\frac{\partial^2\tilde{\xi}_l}{\partial t^2} = |g|k\left[-\frac{\tilde{\xi}_u}{\sinh(kh)} + \frac{\tilde{\xi}_l}{\tanh(kh)}\right] \quad \frac{\partial^2\tilde{\xi}_u}{\partial t^2} = |g|k\left[-\frac{\tilde{\xi}_u}{\tanh(kh)} + \frac{\tilde{\xi}_l}{\sinh(kh)}\right]$$

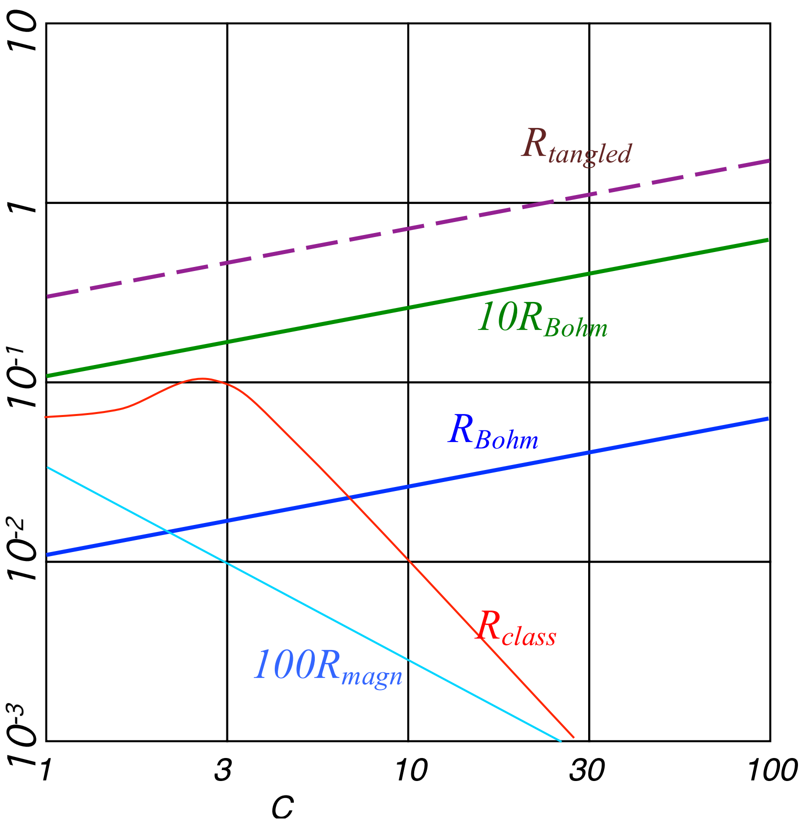
* D.D. Ryutov, Proc. 2011 DZP Conference, AIP Conference Proc., 2012.

Plasma confinement



Transport coefficients for the reference case: $\rho_0 = 1mg/cm^3$ ($n_0 = 2.4 \times 10^{20} cm^{-3}$), $T_0 = 300eV$, $B_0 = 30T$, $r_0 = 3mm$, L=1cm.

Relative importance of various processes



R=the ratio of the instantaneous pdV heating time to the loss time (small *R* is good)

For MAGLIF plasma parameters, reaching 10 Bohm is hardly possible*: collisionality is high, $\nu_{ii} > \omega_{drift}$

*D.D. Ryutov. Physics of Plasmas, **9**, 4085, 2002; D.D. Ryutov et al, Nucl. Fus., **43**, 2003

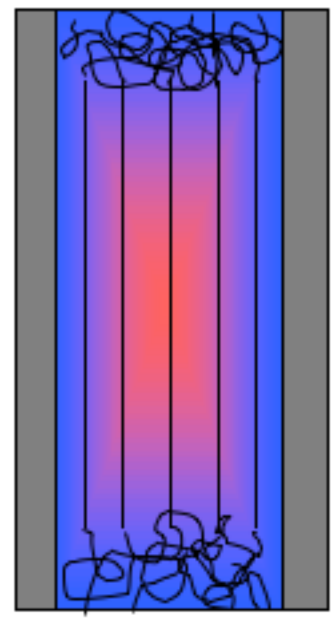
Formation of tangled magnetic field zones near the cold ends

Parallel electron heat flux near cold ends is large and causes distortion of the electron distribution function. This then leads to development of “fire-hose” or “mirror” instabilities if

$$\beta > \left(\frac{n \mathrm{v}_{Te} T_e}{q_{\|}} \right)^2$$

where $q_{//}$ is axial heat flux. Is satisfied at the distance ~ $L/5$ near each end.

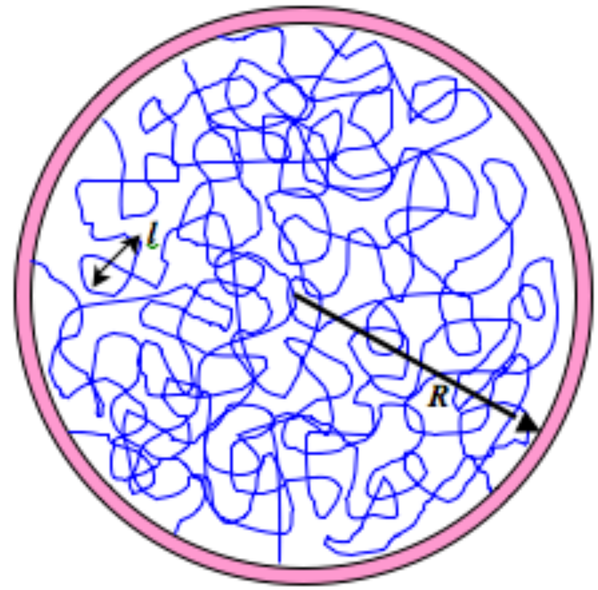
Tangled field is good for suppressing the axial heat loss.



Stochastic field over the whole volume?

It may happen that the field becomes stochastic across the whole volume, not only near the ends. This may occur at high betas ~ 30. This doesn't necessarily mean poor confinement.*

$$\tau_e \sim \frac{L^2}{2\chi_e} \sim N^2 \frac{R^2}{2\chi_e}; \quad N \equiv \frac{R}{l} >> 1$$



May allow for different ways of creating the preheated plasma.

* D. Ryutov, Fus. Sci. Techn., **56**, 1489-1494, November 2009

SUMMARY ON PLASMA CONFINEMENT

For the set of parameters identified by S. Slutz et al. the level of the plasma collisionality is quite high during the whole implosion process, thus reducing the risk of the strong anomalous cross-field transport driven by drift-type modes.

The magnetic field is line-tied to the plasma; in the course of the core plasma heating, the core plasma pushes aside the colder plasma, thereby leading to a significant magnetic field build-up near the plasma-liner interface.

The usable beta value may be limited from above by development of instabilities driven by minor deviations of the plasma from the equilibrium state.

Preheat

In addition to the laser preheat, one can consider preheat by one or two light z-pinches situated at the end(s).

Three versions:

1) Injection of the hydrogen plasma with necessary parameters by matching the implosion times of the pinches, so that the axial magnetic field in the fast pinches and the main volume would be the same

2) Injection of a plasma with tangled magnetic field into a liner without any magnetic field

3) Using fast pinches as a light source for the plasma heating inside the main liner

Summary

The proposed system looks quite robust with respect to the problems associated with plasma confinement. This favorable conclusion is mainly related to a high plasma collisionality and simple linear geometry, both enabled by a short implosion time.

The liner stability seems to be satisfactory; can be significantly improved by embedding a strong axial field in the liner material. Of a concern can be development of the flute mode at stagnation.

Alternative schemes of the plasma preheat may be feasible (physics-wise, not necessarily engineering-wise).